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TECHNICAL REPORT 2665

DEVELOPMENT OF EXPLOSIVES OF HIGH MECHANICAL STRENGTH (U) (SECOND REPORT)

J. DONALD HOPPER

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PICATINNY ARSENAL
DOVER, N. J.

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DEVELOPMENT OF EXPLOSIVES OF HIGH MECHANICAL STRENGTH (U)

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DEVELOPMENT OF EXPLOSIVES OF HIGH MECHANICAL STRENGTH (U)

(Second Report)

by

J. Donold Hopper

December 1959

Feltman Reseorch ond Engineering Loborotories
Picatinny Arsenal
Dover, N. J.

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Ordnance Project TA2-8051

Dept of the Army Project 512-15-018

Approved:

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(C) OBJECT

To develop high-energy explosives which can be consolidated into explosive charges having high mechanical strength.

(C) SUMMARY

An explosive consisting of 70 parts by weight of HMX and 30 parts of Exon 461, a commercial fluorocarbon polymer, was prepared in granular form on a pilot-plant scale, compression-molded into large high-density cylinders, and tested to provide another agency with samples of the molded explosive and information on certain of its properties. Interest in this material stemmed from prior work done at this Arsenal to evaluate HMX bonded with Exon 461 in proportions ranging from 5% to 15%.

The explosive was consolidated to its theoretical maximum density very easily and remarkable density uniformity was attained. The explosive showed excellent chemical stability in vacuum stability tests. It was readily initiated to detonation in molded form, and its detonation rate at 1.83 g/cc density, when unconfined, was 7870 meters per second. It was found that the molded explosive is a relatively high-strength material having good machinability, exceptional toughness, compressibility, and elasticity, and a low modulus of elasticity. Over the temperature range of 70°F to -65°F, its tensile strength increased from 1540 psi to 2230 psi and its compressive strength from 10,700 psi to over 16,300 psi. Over the temperature range of 149°F to 160°F, however, the explosive softened markedly and lost much of its mechanical strength.

(C) CONCLUSIONS

The feasibility of coating HMX with Exon 461 by the slurry method in any proportion up to 30% of Exon was demonstrated. Molded 70/30 HMX/Exon is outstanding in toughness and mechanical strength among the explosives we have investigated. In addition to serving the purpose for which it was undertaken, the work done shows how easily we can tailor an explosive to meet requirements for special physical, mechanical, and explosive properties.

(C) RECOMMENDATION

In view of the need for more insensitive PBX-type explosives, it is recommended that tests of 70/30 HMX/Exon 461 and other plastic-bonded explosives in molded form be conducted to determine whether substantial differences in sensitivity to impact exist. The proposed investigation should include development of a reliable and inexpensive test for judging the sensitivity of molded explosives.

(C) INTRODUCTION

1. (C) About a year ago the work being done at Picatinny Arsenal to develop and evaluate plastic-bonded explosives consisting of HMX coated with Exon 461 in various proportions (Ref 1) came to the attention of some research people at the Lawrence Radiation Laboratory, who requested samples of 70/30 HMX/Exon and information on certain of its properties. At that time, the investigation at Picatinny had covered the range of 85/15 to 95/5 HMX/Exon only. To fulfill this request, the 70/30 composition was prepared and molded on a pilot-plant scale, and the molded product was tested.

2. (C) Although the scope of this investigation was limited, a fairly large body of data was accumulated and considerable experience with the 70/30 composition was acquired. It was found to be an interesting material with a unique combination of explosive and mechanical properties. In view of the growing interest in plastic-bonded explosives for a variety of applications, it was decided that the information collected should be published in a formal report.

(C) RESULTS

3. (C) One 10-pound batch and one 20-pound batch of 70/30 HMX/Exon 461 molding powder were prepared by a water-slurry solvent-coating process similar to that used previously (Ref 1) for making other HMX/Exon compositions. This explosive differed from others in this series prepared previously not only in composition but also in the extreme fineness (average particle diameter 2.2 microns) of the HMX used in preparing it. A 10-pound batch of 85/15 HMX/Exon 461 molding powder, designated Batch No. 3, was also prepared from the same materials and under similar conditions.

4. (U) Samples of the three batches of molding powder were tested in the laboratory to determine HMX content, bulk density, granulation, thermal stability, and sensitivity to initiation by impact. The results of these tests are presented in Table 1 (p 3).

5. (C) The 70/30 HMX/Exon molding powder was compression-molded without major difficulty into cylinders of various sizes in evacuated molds at 100°C with a pressure of about 26,500 psi. The 70/30 composition behaved like previously studied compositions except that the amount of flashing was noticeably greater and the flashing was tough instead of brittle. The flashing tended to remain attached to the molded pieces, as a collar-like extension which resisted removal if left on till the pieces had cooled. It was also more difficult to separate large molded pieces from the lower punch because the flashing tended to prevent loosening the piece from the punch by sliding it sidewise as is usually done.

6. (C) The cylinders of 70/30 HMX/Exon formed under the conditions mentioned above included 4 pieces 2 inches in diameter by 1 inch long made from molding powder Batch No. 1; one 2-pound piece, 8.5 inches in diameter by ½ inch long, made from Batch No. 1; and one 18-pound piece, 8.5 inches in diameter by about 5 inches long, made

TABLE 1

Results of Laboratory Tests of 70/30 and 85/15 HMX/Exon 461 Molding Powders

	70/30 (Batch No. 1)	70/30 (Batch No. 2)	85/15 (Batch No. 3)
HMX Content, % by weight	69.4	69.3	85.0
Bulk Density, g/cc	0.57	0.48	0.53
Granulation, % by weight:			
Retained on No. 4 U. S. Standard Sieve	0.4	33.5	0
Through No. 4 on No. 5 Sieve	2.0	16.5	0
Through No. 5 on No. 6 Sieve	5.3	13.0	0
Through No. 6 on No. 10 Sieve	47.3	28.8	0
Through No. 10 on No. 12 Sieve	18.1	3.7	0
Through No. 12 on No. 20 Sieve	24.7	3.8	0
Through No. 20 on No. 35 Sieve	1.8	0.5	0
Through No. 35 on No. 100 Sieve	0.4	0.2	92
Through No. 100 Sieve	0	0	8
Thermal Stability at 120°C			
Gas evolved from 5-g sample in 40 hr in 120°C Vac Stab Test, ml	0.48		0.31
Sensitivity to Initiation by Impact			
Height of fall of 2-kg hammer required to cause explosion, inches	9 to 11		11

from Batch No. 2. Measurements of the dimensions and density of these cylinders gave the data presented in Table 2 (p 4).

7. (C) Detonation velocity tests of unconfined ½" × ½" × 6" sticks of the 70/30 composition cut from the 2-pound cylinder gave the following results:

	Detonation Velocity m/sec
Test No. 1	7865
Test No. 2	7875
Average	7870

8. (C) Small cylindrical samples of the molded 70/30 composition cut from the 18-pound cylinder, and similar samples of 85/15 and 95/5 HMX/Exon 461 cut from similar cylinders of these compositions were subjected to a small-scale plate-push test at the Lawrence Radiation Laboratory (LRL). The relative specific energy of these explosives, determined by this test, is indicated by the values given in Table 3 (p 4), for which the author is indebted to John Kury of the Chemistry Division, LRL.

TABLE 2

Dimensions and Densities of Compression-Molded Cylinders of 70/30 HMX/Exon 461

Cylinder Number	Weight, grams	Weight, pounds	Diameter, inches	Height, inches	Density, g/cc	% TMD[a]
1	93.320		1.984	1.010	1.835	100.0
2	93.043		1.990	1.004	1.835	100.0
3	93.751		1.990	1.013	1.834	>99.9
4	93.496		1.994	1.006	1.834	>99.9
5		1.99	8.464	0.510	1.826	99.5
6		17.98	8.466	4.840	1.833	99.9

[a]TMD (Theoretical maximum density) is 1.835 g/cc.

TABLE 3

Relative Specific Energy of Various Explosives

Composition of Explosive	Density of Samples, g/cc	Specific Energy, (relative to TNT)
70/30 HMX/Exon 461	1.83	1.07
85/15 HMX/Exon 461	1.84	1.25
95/5 HMX/Exon 461	1.86	1.38
TNT		1.0
Composition B[a]	1.70	1.26
LASL 9404[b]		1.38
70/30 HMX/epoxy resin	1.65	1.06
90/10 HMX/epoxy resin	1.74	1.23
95/5 HMX/epoxy resin	1.80	1.35
70/30 HMX/nylon	1.57	0.92
95/5 HMX/nylon	1.81	1.35

[a]Nominal composition is 60/40 RDX/TNT with 1% wax added.

[b]94/3/3 HMX/nitrocellulose/tris-β-chloroethyl phosphate

9. (C) Specimens for compression and tensile tests of the molded 70/30 composition were cut from the 18-pound cylinder, and the density of the compression test specimens was determined to get an indication of the density uniformity of the cylinder. The values obtained were evenly divided between 1.835 and 1.836 g/cc—there were 21 of each.

10. (C) The tensile and compressive properties of the molded 70/30 composition at −65°F, 0°F, 70-72°F, 125°F, 149°F, and 160°F were determined by testing the specimens with an Instron testing machine. The results of these tests are summarized in Tables 4 and 5 (pp 6 and 7). At a later date, the 7 compression test specimens which were left over from the original group of 42 were tested at 72°F with a Tinius Olsen Electromatic universal testing machine. The results of this group of compression tests are presented in Table 6 (p 8). In all of these tests the speed of the loading crosshead was 0.05 inch per minute.

11. (C) Twelve 2-inch-diameter compression-molded cylinders, 4 each of the 70/30, 85/15, and 95/5 HMX/Exon compositions, were thermally cycled from 80°F through −65°F and 165°F back to 80°F over a 24-hour period to detect any pronounced tendency of these explosives to crack, shrink, or grow when subjected to varying air temperatures. No changes were detected when the cylinders were inspected visually at the end of the thermal cycle. Measurements of the specific gravity and the dimensions of each test piece before and after cycling gave the data presented in Table 7 (p 9).

(C) DISCUSSION OF RESULTS

12. (C) Moldingpowders of the 70/30 and 85/15 compositions which were entirely satisfactory for the purposes of this study were made by coating HMX with the binder in the required proportions. The procedure used involves adsorption of a dilute toluene solution of Exon on the surface of the HMX while the HMX is suspended in hot water, followed by a distillation which removes the toluene and leaves the Exon attached to the HMX as a coating. It is essentially the same as the slurry procedure employed in the previous study (Ref 1) for preparing molding powders which were much leaner in binder content. Although the 70/30 composition was produced in only 10- and 20-pound batches, it is believed that the feasibility of coating HMX with Exon 461 by the slurry method in any proportion up to 30 percent of Exon has now been demonstrated.

13. (C) Preparation of the 70/30 composition by this method was undertaken with some misgivings because there would be 30 pounds of Exon solution for each 7 pounds of HMX in a batch, and it was doubted that the surface area of the HMX would be sufficient to adsorb so much solution. It was feared that the excess solution would adhere to the surfaces of the mixing equipment, causing the coated HMX to stick to them.

TABLE 4

Results of Compression Tests[a] of Specimens[b] Cut from 18-lb Compression-Molded Cylinder of 70/30 HMX/Exon 461[c]

Test Temperature	Stress at Rupture, psi	Compression at Rupture, %	Work to Produce Rupture, ft-lb/in^3	Modulus of Elasticity, psi
−65° F				
Average of 5	>16,300[d]	no rupture	no rupture	111,000
Maximum	>16,300[d]	no rupture	no rupture	116,000
Minimum	>16,300[d]	no rupture	no rupture	104,000
0° F				
Average of 5	15,700	11.6	87.3	104,000
Maximum	15,900	13.6	119.0	113,000
Minimum	15,300	10.7	72.9	92,300
72° F				
Average of 10	10,700	14.9	98.4	118,000
Maximum	11,100	16.4	132.0	146,000
Minimum	10,400	13.6	84.3	107,000
125° F				
Average of 5	4,280	17.6	46.0	62,900
Maximum	4,870	18.4	52.3	78,200
Minimum	3,960	16.8	39.6	52,100
149° F				
Average of 5	892	7.5	3.5	19,400
Maximum	940	8.2	4.1	20,300
Minimum	845	7.1	3.2	18,500
160° F				
Average of 5	524	8.8	2.6	11,400
Maximum	546	12.6	3.8	12,700
Minimum	497	7.8	2.2	8,800

---

[a] All tests were conducted with the Instron testing machine.

[b] 5/8-inch-diameter by 1 1/4-inch-long cylinders were used in all cases.

[c] The cylinder was made from molding powder identified as 70/30 HMX/Exon 461, Batch No. 2.

[d] None of the specimens ruptured when subjected to a 5000-pound load, the maximum the available test cell would withstand.

TABLE 5

Results of Tensile Tests[a] of Specimens[b] Cut from 18-lb Compression-Molded Cylinder of 70/30 HMX/Exon 461[c]

Test Temperature	Stress at Rupture, psi	Elongation at Rupture, %	Work to Produce Rupture, ft-lb/in^3	Modulus of Elasticity, psi
−65° F				
Average of 4	2230	7.1	5.7	24,200
Maximum	2610	7.7	7.2	25,400
Minimum	2000	6.6	4.6	23,000
0° F				
Average of 5	2020	7.1	5.1	21,400
Maximum	2340	8.5	6.7	24,100
Minimum	1580	6.4	3.5	17,200
70° F				
Average of 10	1540	3.1	1.7	36,700
Maximum	1790	3.6	2.3	40,500
Minimum	1250	2.7	1.2	32,400
125° F				
Average of 5	859	6.5	2.7	19,400
Maximum	904	7.8	3.4	20,200
Minimum	807	5.1	1.9	16,700
149° F				
Average of 5	330	6.4	1.1	8,300
Maximum	346	6.7	1.2	8,400
Minimum	305	6.0	0.9	8,100
160° F				
Average of 5	262	6.4	0.8	6,900
Maximum	275	7.0	0.8	7,400
Minimum	249	6.1	0.7	6,200

[a] All tests were conducted with the Instron testing machine.

[b] ½-inch-diameter-by-2-inch-long spool-shaped pieces were used.

[c] The cylinder was made from molding powder identified as 70/30 HMX/Exon 461, Batch No. 2.

TABLE 6

Results of Compression Tests with Tinius Olsen Machine[a] of Specimens[b] Cut from 18-lb Cylinder of 70/30 HMX/Exon 461

Specimen Number	Stress at Rupture, psi	Compression at Rupture, %	Work to Produce Rupture, ft-lb/in^3	Modulus of Elasticity, psi
36	10,000	13.8	96.8	679,000
37	10,300	13.8	104.6	649,000
38	10,100	13.9	104.8	547,000
39	9,990	12.3	88.9	598,000
40	10,200	14.2	105.5	662,000
41	10,100	14.2	102.6	675,000
42	10,100	13.6	99.7	611,000
Average	10,100	13.7	100.4	632,000

[a]Strain was measured with a deflectometer.

[b]$\frac{5}{8}$-inch-diameter by $1\frac{1}{4}$-inch-long cylinders were used in these tests.

TABLE 7

Dimensions and Specific Gravities of Molded HMX/Exon 461 Cylinders Before and After Thermal Cycling

Composition of Cylinder, (HMX/Exon 461)	Cylinder Number	Diameter at 0°, in.		Diameter at 90°, in.		Length, in.		Specific Gravity	
		Before	After	Before	After	Before	After	Before	After
70/30	A1	1.991	1.992	1.990	1.991	1.005	1.005	1.833	1.833
	A2	1.989	1.990	1.988	1.991	1.005	1.005	1.833	1.833
	A3	1.990	1.991	1.990	1.991	1.010	1.010	1.832	1.832
	A4	1.990	1.991	1.991	1.992	1.006	1.006	1.833	1.833
85/15	B1	2.000	2.001	2.000	2.001	1.002	1.002	1.835	1.834
	B2	2.000	2.001	2.000	2.001	1.003	1.003	1.835	1.834
	B3	2.000	2.001	2.000	2.001	1.003	1.003	1.835	1.834
	B4	2.000	2.001	2.000	2.001	1.002	1.002	1.835	1.835
95/15	C1	2.000	2.001	2.001	2.0015	1.006	1.006	1.849	1.848
	C2	2.001	2.0015	2.001	2.0015	1.011	1.011	1.848	1.847
	C3	2.001	2.0015	2.001	2.0015	1.011	1.011	1.848	1.847
	C4	2.001	2.0015	2.000	2.001	1.009	1.009	1.849	1.848

The coated HMX might also agglomerate into masses too large to be dispersed by the stirrer. If this happened, it was expected that these masses and the explosive adhering to the equipment would become hard during the distillation stage, forming large lumps unsuitable for molding and a crust which would be difficult to remove from the equipment.

14. (C) Fortunately, the HMX did adsorb most of the Exon solution, and the masses of coated HMX which formed eventually broke up into small clusters which gave little trouble. This outcome is attributed largely to three measures which were taken to minimize the anticipated difficulties. First, extremely finely divided HMX, the finest on hand at the time, was used for the explosive component to provide the largest possible surface area for adsorbing the Exon solution. Second, gelatine, a dispersant, was added to each batch in the ratio of 1:200 parts of product, a larger than normal proportion. Third, the batch size and batch volume were kept small so that the action of the stirrer would result in vigorous and effective agitation.

15. (C) Despite the efforts made to spread the binder over a large surface and to disperse the coated HMX into small clusters so that the grain size of the molding powders would be small, the three powders differed markedly in granulation (Table 1, p 3). A large proportion of the grains in the 20-pound batch of the 70/30 composition were as coarse as large peas, while the grains of the 10-pound batch were comparable in size to cracked wheat or coarse sand. This difference probably resulted from the differences in volume and concentration, which affected the agitation. The batch of the 85/15 composition resembled table salt in granulation and appearance. The extreme fineness of this material as compared with the material in the 10-lb batch of the 70/30 composition must be due to the smaller proportion of binder present, as other conditions were identical. It is interesting to note that the 85/15 molding powder prepared in this study was much finer than that prepared in the previous study. This difference is attributed to the larger surface area of the HMX used in this study.

16. (C) The low bulk density of the three molding powders (Table 1, p 3), 0.5 to 0.6 g/cc, is the inevitable result of their narrow granulation range. Normally, this would be a serious deficiency as it would be difficult to mold such bulky material into large high-density cylinders in existing molds without deviating from approved procedures. Fortunately, molded cylinders of moderate height were large enough for this study, and no difficulty was encountered in making such pieces.

17. (C) Samples of the 10-pound batches of the 70/30 and the 85/15 composition were subjected to the 120°C vacuum stability test in conformity with the standard practice of checking the stability of materials which are to be molded while hot. As the amounts of

gas evolved by the samples in these tests were less than a half milliliter, there is no question that their chemical stability at temperatures up to 120°C should be rated excellent. This is in line with the findings in all previous similar tests of HMX/Exon 461 compositions.

Density Uniformity and Explosive Properties

18. (C) The results of small-scale laboratory impact sensitivity tests of samples of the 70/30 and the 85/15 molding powders were disappointing (Table 1, p 3). 70/30 HMX/Exon 461 was expected to be quite insensitive—certainly less sensitive than 85/15 HMX/Exon. It was thought that Exon 461, being non-explosive and somewhat resilient, would desensitize HMX in proportion to the amount present. Comparing the 9-inch and 11-inch values obtained in two tests of samples of the 70/30 powder with the 11-inch value obtained in the test of the 85/15 powder, one is forced to conclude that, if there is any real difference at all, the 70/30 powder is probably the more sensitive. Comparing these values with the results of earlier similar tests of the 85/15, 90/10, and 95/5 compositions, one finds no correlation between the sensitivity data and the compositions. This is attributed to the fact that the test samples must usually be prepared by grinding the molding powders to reduce the grain size. The ground samples tend to yield results which are often not very different from those obtained in tests of uncoated HMX itself.

19. (C) The conditions used in compression-molding the 70/30 powders were those which had yielded fairly good results in the previous study of Exon-bonded HMX. Time did not permit much experimentation to determine optimum conditions. In every molding trial, the 70/30 composition was consolidated to virtually theoretical maximum density. This was an unexpected result as the densities attained in the previous study were seldom higher than 98.5% of the maximum. The large proportion of binder and the extreme fineness of the HMX in the 70/30 powders apparently gave them exceptionally good flow properties.

20. (C) In our studies of plastic-bonded explosives, we have been constantly striving to make explosive charges in which the variation in composition and density is extremely small. The degree of density uniformity which can be attained if an explosive is consolidated to virtually theoretical maximum density is indicated by the results of density tests of samples cut from the 18-pound cylinder of the 70/30 composition (Table 2, p 4). The difference between the high and the low values in this group of 42 results was only 0.001 g/cc. The fact that the high values were 0.001 g/cc above the theoretical maximum density of this composition is an indication that the variation found is within experimental error.

21. (C) Efforts to determine and evaluate the explosive characteristics of molded 70 /30 HMX/Exon 461 were limited to detonation-velocity and plate-push tests. The velocity tests showed that this explosive can be readily initiated to high-order detonation and that its detonation rate in small unconfined sticks of 1.83 g/cc density is about the same as that of cast Composition B (Compare with 7840 meters per second in Ref 2 and 7930 meters per second in Ref 3). In the plate-push test, the 85/15 HMX/Exon samples were indicated to be about equivalent energywise to the samples of Composition B and the 70/30 HMX/Exon to be superior to TNT but inferior to Composition B. It is noteworthy that, in this test, both 70/30 and 85/15 HMX/Exon performed better than the corresponding HMX/nylon and HMX/ epoxy resin compositions. The difference found may be a reflection of an energy benefit derived from the halogen atoms in Exon 461 or it may be that the higher density of the samples of Exon-bonded HMX had a bearing on their superior performance.

22. (C) If it could be demonstrated that molded 70/30 HMX/Exon is as insensitive to impact as it is thought to be, this characteristic would probably generate considerable interest in testing the explosive further for use in ammunition. Until this has been done, any consideration of its possible use would probably be based on its rather unusual mechanical properties.

Mechanical Properties

23. (C) Experience gained in the course of preparing molded cylinders and cutting test specimens showed that this material has good machinability and is exceptionally tough. The large proportion of binder in the 70/30 composition renders the molded product somewhat softer and more resilient than most molded explosives. It was cored, sawed, and cut on a lathe to precise dimensions without difficulty. Thin slabs of it withstood much rougher handling than most explosives will take without breaking or chipping. These are largely qualitative observations, however, and they should be confirmed by appropriate tests. To date, efforts to measure and evaluate the mechanical properties of this explosive have been limited to compression and tensile tests at various temperatures.

24. (U) All the tensile tests and most of the compression tests were conducted with the two Instron testing machines used in the previous study of Exon-bonded HMX and in accordance with the same procedures. Most of the results are therefore directly comparable with the results of corresponding tests reported in Reference 1.

25. (C) The data (Tables 4 and 5, pp 6 and 7, and Ref 1) shows that the compressive and tensile properties of molded 70/30 HMX/Exon resemble those of molded 85/15 HMX/Exon more closely than those of the other explosives

studied. This could have been predicted on the basis of the similarity of the two compositions. But there are significant differences which apparently stem from the large difference in the proportions of HMX and binder in the two explosives. It seems appropriate to discuss the similarities and differences further and to limit the comparison to these two materials because molded 85/15 HMX/Exon 461 is still outstanding in overall mechanical strength and toughness among the stable high-energy explosives we have investigated.

26. (C) Since it was found that temperature changes affect the mechanical properties of both explosives greatly and not always equally, discussion of the findings in detail would be complicated by the need to qualify each remark with a statement concerning the test temperature. To facilitate review, therefore, the information is summarized in Table 8 (p 14). The values are averages taken from Reference 1 and from Tables 4 and 5 (pp 6 and 7) of this report.

27. (C) It is evident from the data in Table 8 (p 14) that molded 70/30 HMX/Exon 461 has significantly better tensile strength than molded 85/15 HMX/Exon 461 except at elevated temperatures, equivalent compressive strength except at elevated temperatures, greater compressibility and elasticity, and a much lower modulus of elasticity. Since the work required to produce rupture in compression and tension is a measure of toughness, it is evident also that the 70/30 composition is much tougher at all the test temperatures except 149°F and 160°F.

28. (C) The compressive properties of molded 70/30 HMX/Exon at room temperature (72°F) were determined first in a series of 10 tests conducted with an Instron testing machine and again in a series of 7 tests conducted 7 weeks later with a Tinius Olsen Electromatic universal testing machine. The test specimens used in the second series of tests were all that remained of the original group of 42, mentioned previously. The results of the second series of tests are included in this report (Table 6, p 8) since future tests of this sort will be conducted with the Tinius Olsen machine because of a change in testing facilities in the interval between the two series of tests and because it was desired to show that the results of the two series differ somewhat, particularly in the modulus of elasticity. The magnitude of the differences is shown in the following comparison of the average values of the compressive properties:

	Instron	Tinius Olsen
Stress at rupture, psi	10,700	10,100
Compression at rupture, %	14.9	13.7
Work to produce rupture, ft-lb/in^3	98.4	100.4
Modulus of elasticity, psi	118,000	632,000

Recalculation of the values from the Instron charts resulted in raising the modulus

TABLE 8

Mechanical Properties of Molded 85/15 and 70/30 HMX/Exon at Various Temperatures

	Composition of Explosive (HMX/Exon 461) 85/15	70/30
Compressive Stress at Rupture, psi		
-65°F	16,500	>16,300
0°	15,500	15,700
70-75°	10,900-12,000	10,700
125°	5,360-7,340	4,280
149°	3,750	892
160°	3,090	524
Tensile Stress at Rupture, psi		
-65°F	1,500	2,230
0°	1,260-1,340	2,020
70-75°	1,130-1,490	1,540
125°	1,100-1,330	859
149°	851	330
160°	664	262
Compression at Rupture, %		
-65°F	4.7	no rupture
0°	4.6-6.3	11.6
70-75°	3.7-4.1	14.9
125°	3.3-3.5	17.6
149°	2.4	7.5
160°	2.2	8.8
Elongation at Rupture, %		
-65°		7.1
0°	3.0	7.1
70-75°	2.8	3.1
125°	2.6	6.5
149°		6.4
160°		6.4

TABLE 8 (Continued)

	Composition of Explosive (HMX/Exon 461) 85/15	70/30
Modulus of Elasticity in Compression, psi × 10^{-3}		
−65°F	327	111
0°	301-326	104
70-75°	304-326	118
125°	191-249	62.9
149°	195	19.4
160°	159	11.4
Modulus of Elasticity in Tension, psi × 10^{-2}		
−65°F		242
0°	441	214
70-75°	443	367
125°	450	194
149°		83
160°		69
Work to Produce Rupture in Compression, ft-lb/in^3		
−65°F	32.9	no rupture
0°	29.9	87.3
70-75°F	18.0-21.9	98.4
125°	8.2-12.2	46.0
149°	4.3	3.5
160°	3.1	2.6
Work to Produce Rupture in Tension, ft-lb/in^3		
−65°		5.7
0°	1.8	5.1
70-75°	1.4	1.7
125°	1.3	2.7
149°		1.1
160°		0.8

value to only 163,000 psi. The lack of agreement in modulus of elasticity stems from an obvious difference in the slopes of the stress-strain curves traced by the two machines. It is apparent from the values for percent compression and work to produce rupture that the two machines showed approximately equal amounts of strain at rupture.

29. (C) The values shown in Table 7 (p 9) were obtained by determining the specific gravity and measuring the dimensions of small molded cylinders of the 70/30, 85/15, and 95/5 HMX/Exon compositions before and after they were thermally cycled once. There was no change in the length of the cylinders, but an increase in diameter ranging from 0.0005 inch to 0.0010 inch per two inches was detected after the cycling treatment. There apparently was also a very slight decrease in the specific gravity of 7 of the 12 cylinders. It may be significant that the specific gravity of the cylinders of the 70/30 composition did not change, but this seems doubtful. The tests served mainly to show that none of these explosives has any pronounced tendency to crack, shrink, or grow excessively when subjected to variations in atmospheric temperature.

(C) EXPERIMENTAL PROCEDURE

Preparation of Molding Powders

30. (C) Successful application of the slurry method to the preparation of 70/30 HMX/Exon molding powders is attributed largely to the fineness of the HMX used. The HMX was procured from Holston Ordnance Works under the following specifications: HMX, 98+% purity, 97 + 3% through No. 325 U. S. standard sieve. (It is understood that the material supplied had been ground by successive passes of an HMX-water slurry through a centrifugal pump.) It was designated Lot HOL-SR-19-58. Laboratory tests of some of the material, which had been de-watered by filtering and drying, gave the following results:

Moisture Content, %	0.01
Average Particle Diameter (Fisher Subsieve Sizer Method), microns	2.2
Percent by Weight Retained on No. 100 US Standard Sieve	0
Percent by Weight Retained on No. 200 US Standard Sieve	2
Percent by Weight Through No. 200 on No. 270 Sieve	1
Percent by Weight Through No. 270 on No. 325 Sieve	1
Percent by Weight Through No. 325 Sieve	96

31. (U) The other materials involved in the preparation of the molding powders were similar to those used in the previous study, and the same equipment was employed.

32. (C) The following procedure was used for the 10-pound batch of the 70/30 composition: 7 pounds of HMX, previously dried to insure accurate weight, was

suspended in 150 pounds of demineralized water containing 0.05 pound of gelatine by adding the HMX gradually while the water was vigorously stirred mechanically. The slurry thus prepared was heated to 80 ±1°C. Meanwhile, 3 pounds of Exon 461 was dissolved in 27 pounds of warm (40-45°C) toluene. This solution was then added gradually to the hot slurry over a 20-minute period while the mixture was stirred and the temperature was maintained at about 80°C. Steam was then admitted into the jacket of the slurry kettle so that the temperature of the contents rose to the boiling point and the toluene was distilled, leaving the Exon as a coating on the HMX. When the batch temperature reached 97°C, chilled water was substituted for the steam. When the batch temperature was about 40°C, the batch was allowed to flow to a vacuum filter. The damp filter cake was then spread on trays with screen bottoms and dried in a tray dryer with circulated air heated to about 180°F. The dried product was used without screening or other additional treatment.

33. (C) The 10-pound batch of the 85/15 composition was prepared in the same way except that 8.5 pounds of HMX, 1.5 pounds of Exon, and only 13.5 pounds of toluene were used, and the toluene-Exon solution was added to the hot slurry over a period of about 10 minutes.

34. (C) Small differences were introduced into the coating procedure when the 20-pound batch of 70/30 composition was made. The quantities of all materials except water were double those of the 10-pound batch of this composition. The quantity of water was increased to 200 pounds instead of 300 pounds so that vigorous agitation could be maintained throughout the addition and distillation operations. In the equipment used for this batch, the effectiveness of the stirring is reduced markedly as the batch volume is increased beyond 25 or 30 gallons. Because of the large proportion of binder in the 70/30 composition, it was essential that the agitation be quite violent to avoid excessive adherence of the composition to the equipment and to break up the large clumps formed initially into small granules of molding powder. Since there was some adherence, it was considered necessary to use a wooden tool occasionally to detach soft clumps from the equipment so that they would not remain attached during the latter part of the distillation operation.

Tests of Molding Powders

35. (U) The procedures used in testing the molding powders were essentially the same as those used for this purpose in the previous study (Ref 1). The molding powders of the 70/30 composition were ground to pass a 20-mesh sieve to reduce the grains to a size appropriate for the impact sensitivity tests.

Molding Exon-Bonded HMX

36.(C) The molding powders were consolidated into 8.5-inch-diameter cylinders

by essentially the procedure described in Reference 1, but the low-pressure dwell was eliminated and the high-pressure dwell was shortened to 10 minutes. The smaller cylinders were molded with a 75-ton single-action hydraulic press under conditions similar to those used in making the larger cylinders, except that the high-pressure dwell period was only 2 minutes and pressing was begun as soon as air pressure within the mold had been reduced to about 100 microns.

Testing the Molded Explosives

37. (U) The density and detonation velocity tests were performed in the manner described in the previous report (Ref 1). The test procedure in the compression and tensile tests conducted with the Instron testing machine was identical to that used in the previous study. The compression test specimens were $\frac{5}{8}$-inch-diameter by $1\frac{1}{4}$-inch-long right cylinders cut at random from the 18-pound cylinder of the 70/30 composition. The tensile test specimens were 2-inch-long spool-shaped pieces having a 9/10-inch-long cylindrical center portion with a diameter of 0.500 ± .005 inch. The length of this cylindrical portion was used as the "gage length" in calculations of elongation, work to produce rupture, and modulus of elasticity in tension. The rate of loading in the compression and tensile tests was 0.05 inch per minute.

38. (U) In the compression tests with the Tinius Olsen Universal testing machine, the distance travelled by the loading crosshead, as indicated by a deflectometer, was considered to be the strain.

39. (U) The samples of molded explosive used in the small-scale plate-push tests were cylinders 0.340 ±.001 inch in diameter and 1.400 ±.003 inches long with their flat surfaces parallel to within ±.001 inch. They were cut from larger pieces of the molded explosives and machined to the required dimensions on a lathe.

40. (U) The test specimens used in the thermal cycling experiment were cylinders 2 inches in diameter and 1 inch long made by compression-molding the explosive compositions under conditions similar to those prevailing in the molding of large cylinders of these materials. The lower than usual density of the cylinders of the 95/5 composition is a result of using extra-fine HMX in making the molding powder from which the cylinders were made. The specimens were placed on a glass plate in an environmental test chamber maintained at 80°F. The temperature of the atmosphere around the cylinders was then lowered gradually over a 3-hour period to −65°F, maintained at −65°F for 1 hour, and then raised to 80°F in 3 hours. After 1 hour at 80°F, the temperature was raised gradually over a 7-hour period to 165°F

and was kept at 165°F for 1 hour. It was then lowered gradually to 80°F, over an 8-hour period.

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2. W. R. Tomlinson, Jr., *Properties of Explosives of Military Interest*, Picatinny Arsenal Technical Report 1740, Revision 1, December 1956
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